Is there room for a new generation CAE system?

by
Glauco Masotti

The actual situation

In the last two decades we have seen a number of CAD-CAM systems taking birth and competing for a share of the market. Nevertheless the following considerations apply:

- The diffusion of CAD-CAM systems is still well below the optimistic forecasts of a decade ago. In most cases only drafting systems are used rather than three-dimensional modelers.
- This difficulty is due in part to inadequacies in the systems appeared up to now and in part to inadequacies of the market itself, still culturally unprepared and slowly evolving towards an organization of the work more suitable to the use of informatics techniques.
- Nevertheless there still is a potential huge market for CAD-CAM systems, but in order to expect a larger emploiment of these systems the *economic advantage* of using them should become much more apparent.

Three-dimensional (3D) geometric modeling systems are usually believed more complicated to use than bi-dimensional (2D) drafting systems, and this partly explains their still relatively small diffusion. In fact they are mainly employed where complex 3D shapes have to be defined, e.g. car bodies, ship hulls, moulds. In these cases 3D modeling is the essence of design, which cannot be in any way captured by means of 2D models. Often, where no complex surface is involved, people still prefer to design parts by means of a numerous set of complex drawings, making a lot of sections and views. This is the case even when a 3D model would represent the part in a more powerful yet simpler model.

Certainly a lot can be done to improve easiness of use of 3D systems (this is also true for 2D systems as well), but we cannot forget that 3D modeling is an inherently more powerful process, but it requires a different approach to design. People used to think in terms of drawings will never accept it, while people who understand the power and simplicity of a 3D model will never go back to drawings.

3D systems are also used by high end users with sophisticated needs. When it's convenient to simulate stress conditions by means of a finite elements analysis, rather than making and trying a number of prototypes, designers will have to build a 3D model.

Nevertheless no existing system is really satisfactory. A common characteristic of existing systems is that they are general purpose. They propose a global solution to every design and manufacturing need. Therefore they are not the optimum to address specific applications, they offer only poor flexibility or reconfiguration capabilities.

The previous considerations are to say that there still are a lot of opportunities for improving existing CAD-CAM systems. We will shortly go deeper into this aspect.

Where does the market go?

Another source of reflections is the trend of evolution that the manufacturing environment will undertake, and to what extent the availability of new CAD-CAM systems will affect this evolution. At present the production process is highly decentralized, and industries are highly

interdependent on each other. Only a few industries concentrate in house all the process from design to the final manufact. More often only the design and engineering activities are kept, while production is performed by other contracting factories and machine shops. On the other hand we will be able to fully exploit the advantages of CAD-CAM systems only integrating design and production. The many steps and reprocessing of information involved in the current situation could be avoided. A simplified integrated solution will bring great economies. To solve this problem two tendencies may take place:

a) bring production back in the factory;

b) affirmation of some standard for exchanging design and manufacting information.

Option a) will give higher returns but it also requires higher investments. Option b) will maintain the actual fragmented scene, but it is hampered by the difficulties of communication among different CAD-CAM system. While APT is a rather standard way to convey machining information, no recognized such standard exists for electronically conveing design information. As a matter of fact drawings are still the most common media to communicate design choices to executors.

Another thing to think about is the extent of the CAM segment itself. Hitherto when we talk of CAM we think of NC machines for machining metal or sometimes other material. There are however other fields where CAM can take different forms and use different machines, e.g. in shoes or clothes manufacturing we will have to cut leather or fabrics. However, as far as I know, CAD-CAM systems in this field are still scarcely used. The relatively scarce attention devoted to this sectors by CAD-CAM specialists also accounts for the lack of good specialized solutions.

Also we should think of possible relations of CAM with "traditional" industrial automation. The two fields have been separated with few interactions. They address different segments of applications. While traditional industrial automation is dealing with continuos or high volume productions that justify a fixed dedicated plant, CAM is dealing with low or medium volume productions where the use of flexible systems like NC machines is more convenient. Also human intervention in this kind of productions covers a substantial part of time, e.g. machine preparation, tool selection, part setups, etc.. Considering a trend towards goods being offered in a wider spectrum of choices and customized solutions, taking the place of massively offered items, we should assist to a growth in importance of flexible manufacturing systems. Can we imagine a new kind of machines for flexible medium sized productions, capable of taking care of the entire production process and strictly coupled with CAD systems?

Where should we go?

So far we have assisted to a slow introduction of CAD systems in the technical office and of CAM systems in the machine shop. If we accept the previous considerations we should agree that, even in this evolving and contradictory picture, CAD-CAM integration is a promising way to follow, i.e. I believe that there will be more space in the future for the development of integrated CAE systems having as objective *the automatic factory.*

We also should agree that the global system good for every application doesn't exist. In order to achieve the maximum efficiency and the best quality of production we need turnkey solutions for a wide range of production environments and situations.

There is however a problem of cost containment, this implies that our specialized solutions be developed *from a flexible and reusable software library* (here is where object-oriented techniques come in).

I think that time is mature for a new generation CAE system capable of offering a solution to all these diverse needs. While the complete specifications of such a system will require a throughful analysis of the many aspects cited in the above, some useful indications can come from considerations based on the experience with current systems.

How a next generation CAE system should be?

The first requirement of a new system will be a superior quality. The system should address the problems that are still eluded or solved unsatisfactorily by current systems. In particular:

- easiness and flexibility of use;
- editing and parametrization;
- geometric coverage;
- robustness of operation;
- complexity of representable models;
- adaptability to specific fields of applications;
- base of knowledge and intelligence contained in the system; functional design;
- simulation and optimization of design;
- integration in the production and management environment.

Here are some thoughts:

Easiness and flexibility of use

The modeling operations are supported almost exclusively by graphic interaction both in a 2D and in a 3D environment. The available modeling methods simulate intuitive operations or technological processes in the real world. There are classic methods like boolean operations and other unusual shaping operators like bending, folding, forging, etc..

Up to now every system offer a set of modelling methods, based on a fixed set of geometric constructions, which are implemented case by case with specialized code. A system of new generation is able to solve *any* geometric problem the user may need to solve for his/her modeling operation. The user interface is built upon a *General Geometric Solver (GGS)* capable of geometric reasoning.

The system keeps track and synthetize the modeling operations in a *Modeling Process Representation (MPR)* , which is the basic model for representing entities in the system. This is a *procedural model* that we may regard as a very large generalization of CSG.

Editing and parametrization

The system based on MPR, allows for an easy modification of certain design choices maintaining coherence with other unaltered characteristics. A change in a parameter or making a costant a parameter are special cases of this more general editing capability. Exploitation of this capabilities allows for compared evaluation of different design choices, reuse of existing designs and of a library of basic parametric shapes. The different solutions analyzed are maintained and ready for reuse at any time. Undo and redo capabilities are possible to any level.

Parametrization and sophisticated editing capabilities are powerful features, but for certain applications they are only an unuseful overhead, therefore they are optionally offered .

Geometric coverage

The geometric library allows for modeling curves and surfaces in 2D and 3D. Ideally we should support various kind of mathematical representation and in particular parametric and implicit forms. In practice, for an industrial project, we have to contain the complexity of the library in manageable limits (even if we use object-oriented techniques). This implies that it's advisable to choose a subset of curves and surfaces to be represented in the library. A reasonable choice is to deal only with entities which possess a parametric representation, and eventually to take advantage of the implicit representation if it exists and it is convenient. Rather than using NURBS as a unified mathematical representation, accepting the growth in code

complexity, there are relevant advantages in having specialized code for planes, quadrics and torii.

The fundamental computational representation of homogeneous solids is the boundary, because it is the most general one. Certain applications will also require to represent non-homogeneous solids. This can be accomplished using internal subdivision to segment the solid volume, or, if more appropriate, associating the solid with a property function defined for each point of the internal volume.

Curves, surfaces and solids live in a common environment. This allows the construction of models of mixed dimensionality where appropriate, e.g. in the complete model of a car the engine is better modeled with solids, while surfaces are obviously more appropriate for modeling the body.

In some cases we need to describe incomplete or unbounded objects. This happens, for instance, in intermediate design steps when we want to define only "important" functional surfaces.

Robustness of operation

In certain critical situations current systems fail due to insufficient precision in the representation of geometry and the accumulation of numerical errors. Robustness of operation ideally requires infinite precision, which is impossible to attain in practice. However the empirical procedures that are actually used in geometric algorithms should be substituded by a more reliable method.

A promising solution requires that each floating point number be known together with an estimate of the error which affect it. To make practical this approach however we need a specialized hardware.

Complexity of representable models and assemblies

Existing systems shows their weakness in representing complex models like the complete assembly of a machine or a complete building. Our system applies an automatic simplification of details in order to manage quickly complex models. The system offers a special environment for managing assemblies.

Base of knowledge and intelligence contained in the system; functional design

There are various parts of the system where the use of AI techniques is essential. The GGS is an example, a Process Planner for automating part machining is another. Even the intersection of general parametric surfaces is a case. The use of a knowledge database allows for a functional design, automating certain part of the design itself.

Adaptability to specific fields of applications

The system can also include specialized bases of knowledge for specific applications. Macro operations and a programmable procedural interface to use the system as a server for complex specialized applications is possible.

Simulation and optimization of design

Besides classic analysis and simulation programs based on a FEM or a kinematic model, the MPR parametric model gives opportunity for optimization of design.

Integration in the production and management environment

Besides classic CAM interfaces the system knows about *functional surfaces.* These surfaces need to be maintained for a correct functionality of the part while the other can be rearranged in

order to optimize the use of available tools and resources.

What strategy to get there?

The project outlined in the above is certainly an ambitious one. However "all apples in low branches have already been grasped, now we need to crowl the trees", i.e. no easy problem remains to be solved, going further requires to solve challenging problems. A difficult goal deserves some thoughts on the strategy to adopt in order to achieve it.

From an organizational point of view we could make the following choices:

- O1) Form a new independent company.
- O2) Undertake a collabarative effort among different companies (COPIMAC, CAD-LAB, ECOCAD, Autodesk, others...).

From a human resource point of view we could count on:

- U1) Experienced people working in the fields of CAD-CAM and AI, for industry or research.
- U2) Freshly graduated people in electronic engineering, mechanical engineering and mathematics.

From an procedural point of view we could make the following choices:

- P1) Start the development from scratch.
- P2) Assuming hypothesis O2, use the already developed software inherited from the partecipant companies.
- P3) Buy a geometric tool kit to be used as a kernel upon which to base the new developments (ACIS, SHAPES, ALPHA-1, others?...).

From an financial point of view we could make the following choices:

- F1) Find financements to develop a product that will then be marketed.
- F2) Develop a product to solve a specific problem on the base of a commissioned contract. This product could then be generalized and marketed to a wider public.

To:
Dr. Ajay Kela
Autodesk Inc.
2320 Marinship Way,
Sausalito, CA 94965

Bologna, March 14th 1990

Dear Ajay,

I am going to explain you what I have in mind and my situation, so you can judge if you agree with me and decide if we can do something together or not.

First of all my considerations are inspired by the following premises:

- The diffusion of CAD-CAM systems is still well below the optimistic forecasts of a decade ago. In most cases only drafting systems are used rather than 3D modelers.
- This difficulty is due in part to inadequacies in the systems that have leaded the market up to now and in part to inadequacies of the market itself, still culturally unprepared and slowly evolving towards an organization of the work more suitable to the use of informatics techniques.
- Nevertheless I still believe there is a potential huge market for CAD-CAM systems, but we should be able to exploit it only if the *economic advantage* of using these systems will become apparent.

The reasoning following these preliminary considerations is that in the future we should devote our efforts in developing integrated CAE systems having as objective *the automatic factory.* This is opposed to the view (which is still dominant) of a slow introduction of CAD (drafting :-)) systems in the technical office and of CAM systems in the machine shop.

We should be able to produce turnkey solutions for a wide range of production environments and situations, in order to achieve the maximum efficiency and the best quality of production. The global system good for every application doesn't exist.

There is however a problem of cost containment, this implies that our specialized solutions be developed *from a flexible and reusable software library* (here is where object-oriented techniques come in).

I think that time is mature for a new generation CAE system inspired by these criteria. In particular this system should address these problems that are still eluded or solved unsatisfactorily by current systems:

- easiness and flexibility of use;
- editing and parametrization;
- geometric coverage;
- robustness of operation;
- complexity of representable models;
- adaptability to specific fields of applications;
- base of knowledge and intelligence contained in the system; functional design;
- simulation and optimization of design;
- integration in the production and management environment.

Each of these points need to be analyzed and we must think of good solutions. At the moment I have some ideas that need to be developed. I will be glad to undertake this task together if you think there is a common basis upon which we can work.

What I propose to do is to take advantage of the experience we have and evolve it in this new project.

As you probably didn't receive my resume', and our contacts have been only occasional in the last five years, I have to tell you what I am referring to, in particular from my side. I am thinking of the two years with CAD-LAB, developing the *GBG* drafting system that in Italy is previous and still more popular than Autocad (especially on workstations). GBG supports mechanical, architectural and electronic design, as well as 2D+1/2 CAM applications. Then the four years with COPIMAC, heading the design and development of *Aliseo* that you saw during

your visit in Bologna (in '87 right?) half-way of it's development. Aliseo, as far as I know, was the first system to join graphical 3D interactivity with parametric modeling capabilities (it was officially presented six months before Pro-Engineer). We also developed a prototype version of the system supporting a direct interface of the system with NC machining centers. The approach was based on the *design by feature* capabilities of the modeler. Aliseo was entirely developed in the C language. Finally the five months I spent at the Dept. of Mech. Eng. of the Univ. of Bologna, and the year spent at USC with Ari designing GTK, have been useful to investigate some new ideas on user interfaces for geometric modeling, intersection of general parametric surfaces, and architectural issues in a geometric modeler. The development of this work lead me to gain a substantial experience in *object-oriented programming* (C++, Eiffel) and to learn some AI techniques (Prolog).

Here are some thoughts:

Easiness and flexibility of use

The modeling operations are supported almost exclusively by graphic interaction both in a 2D and in a 3D environment. The available modeling methods simulate intuitive operations or technological processes in the real world. There are classic methods like boolean operations and other unusual shaping operators like bending, folding, forging, hammering, etc..

Up to now every system offer a set of modelling methods, based on a fixed set of geometric constructions, which are implemented case by case with specialized code. A system of new generation is able to solve *any* geometric problem the user may need to solve for his/her modeling operation. The user interface is built upon a *General Geometric Solver (GGS)* capable of geometric reasoning.

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Parametrization and sophisticated editing capabilities are powerful features, but for certain applications they are only an unuseful overhead, therefore they are offered as an optional.

Geometric coverage

The geometric library allows for modeling curves and surfaces in 2D and 3D. Ideally we should support various kind of mathematical representation and in particular parametric and implicit forms, following an approach like in GTK. However in that case I followed Ari's directive of being general, having in mind of covering both research and industrial needs. In practice, for an industrial project, we have to contain the complexity of the library in manageable limits (even if we use object-oriented techniques). This implies that it's advisable to choose a subset of curves and surfaces to be represented in the library. To me the best choice is to deal only with entities which possess a parametric representation, and eventually to take advantage of the implicit rep if it exists and it is convenient. Rather than using NURBS as a unified mathematical representation, accepting the growth in code complexity, there are relevant advantages in having specialized code for planes, quadrics and torii.

The fundamental computational rep of homogeneous solids is the boundary, because it's much more general than a CSG rep (you will never convince Ari of this :-)). Certain applications will also require to represent non-homogeneous solids. This can be accomplished using internal subdivision to segment the solid volume, or, if more appropriate, associating the solid with a property function defined for each point of the internal volume.

Robustness of operation

Robustness of operation require that each floating point number be known together with an estimate of the error which affect it. I spent some time while at USC studing the problem. To make practical this approach however we need a specialized hardware (to me the use of rational numbers is not promising instead).

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All right, now there are two possibilities: you and Autodesk are interested in pursuing something like I wrote before, and in this case we should decide what to do; or else you are not interested, and in this case you can propose me *something else* or we can forget everything, go along our own way and be friends like before.

Let me suppose you are interested. A collaboration can take *various forms.* The simplest form is that you offer me *a position at Autodesk* and I came to Sausalito to work with your group. However there are some drawbacks to this solution: first of all I would prefer to stay here if possible, then we wouldn't take advantage of the know-how of other people here that I can involve in this project. Without any doubt what I described before is an ambitious project and this justify a collaborative effort even on an international basis (with all the related for and against).

The other possibility is therefore to undertake *a collaborative effort between Autodesk and a company here*. This may be one of the companies for whom I worked in the past, as I am still in good relationships with them, or else a completely new company that I can found calling some of my old colleagues plus some new good people (as most of all I am in good relations with these people).

But after all to do anything we need two things: *people* being able of doing it and *money* to finance the operation, which, in this case, is the big problem. It may be that from your side

you have intention to support this project, and this will solve part of the problem. From this side I am currently having a lot of contacts to see what is possible to do here. I see two possibilities: one of the old companies decides to sponsor the project, or there are the conditions to create a new company on the basis of a contract in some way related to the more general framework I depicted before, but not necessarily coincident, i.e. a contract commissioned to solve a specific problem, but that can fire the new developments I told you, that could be subsequently generalized. For the moment I cannot tell you anything more than this, but a big hand can came from you.

What do you think?

Cheers,
--Glauco

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